ANNUAL PROGRESS SUMMARY
Project period January 1, 2002 – December 31, 2002

TITLE: THE QUATERNARY GEOLOGIC FRAMEWORK FOR THE CITY OF SEATTLE AND THE SEATTLE-TACOMA URBAN CORRIDOR

Cooperative Agreement Number: 01HQAG0017

Investigators: Derek B. Booth, Kathy G. Troost, Scott A. Shimel, Michael A. O'Neal, University of Washington, Department of Earth and Space Sciences, Box 351310, Seattle, WA 98195-1310

Telephone: (206) 543-7923, FAX: (20) 685-3836 dbooth@u.washington.edu
http://www.geology.washington.edu/sea-geo

NEHRP Element: I, Pacific Northwest region **Keywords**: Geologic Mapping, Surficial Deposits, Age Dating, Tectonic Structures

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Authors: Derek B. Booth, Kathy G. Troost, Scott A. Shimel, Michael A. O'Neal: University of Washington, Department of Earth and Space Sciences, Box 351310, Seattle, WA 98195-1310
Contact Information: 206-543-7923, FAX 206-685-3836, dbooth@u.washington.edu
206-616-9769, FAX 206-685-3836, ktroost@u.washington.edu

ABSTRACT

Our investigations during this fourth year of an anticipated six-year project represent the continuation and development of a wide range of tasks that focus on the Quaternary framework of the Seattle area. This emphasis is critical for any geologic or seismic-hazard studies because most of the central Puget Lowland has a recent sedimentary cover one hundred to over one thousand meters thick.

At this stage in the project, we have accomplished the following tasks:

— Submittal of eight MF-series 7.5-minute maps at 1:24,000 in the Seattle-Tacoma area into USGS review;

— Development and population of a database of existing subsurface geologic and geotechnical data that accommodates both spatial and nonspatial data by following a GIS-based approach, with over 40,000 individual records (points) of subsurface geologic information (22,000 within the City of Seattle alone), doubling the number of entries during this year;

— Completion of surficial geologic maps of the Seattle SW and NW quadrangles at 1:12,000 scale and near-completion (as of October 2002) of a surficial geologic map of the Seattle SE quadrangle at 1:12,000 scale;

— Building of the first true 3-D map (solid model) of the Seattle NW quadrangle;

— Multiple abstracts and other publications;

— Response to requests for information from USGS scientists within and outside of the Earthquake Program, other Federal agencies, local governments, private consultants, and the public.

— Short courses, field trips, technical presentations, public presentations, and formation of a technical advisory group for the project of the region's major consulting firms and public agencies; and

— Three-fold leveraging of USGS NEHRP funds from additional sources in 2001 and 2002 that has expanded both the data collection and the geographic scope of the project.

BACKGROUND

Our investigations during this fourth year of an anticipated six-year project represent the continuation and development of a wide range of tasks that focus on the Quaternary framework of the Seattle area. This emphasis is critical for any geologic or seismic-hazard studies because most of the central Puget Lowland has a recent sedimentary cover one hundred to over one thousand meters thick.

We recognize five major components to develop this framework and to disseminate the resulting information:

1. Develop the regional stratigraphy and chronology for the central Puget Lowland;
2. Create a subsurface geologic database for the City;
3. Prepare new surficial geologic maps of the City;
4. Develop the geologic model (3-D map and database) of the City; and
5. Provide education and technical outreach.

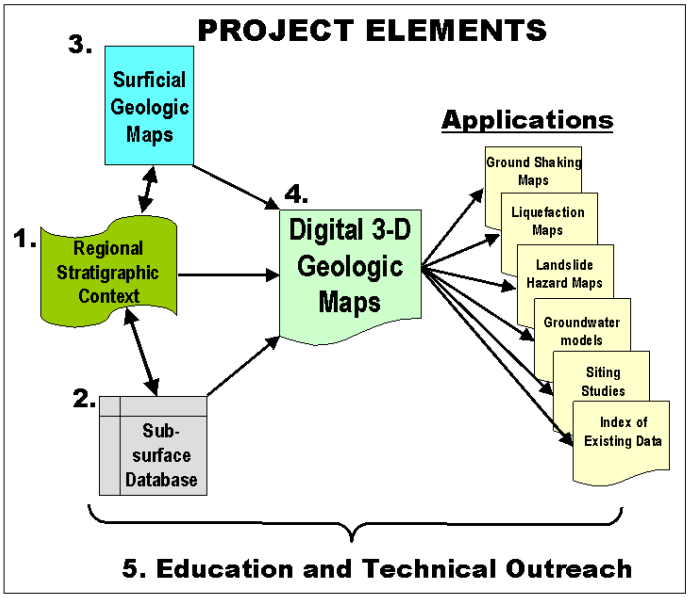

Figure 1: Elements of the Seattle Geologic Mapping Project

The surficial and 3-D geologic mapping in the four quadrants of the City of Seattle (Figure 2) provides the framework for the overall project. They are anticipated to be completed on a roughly annual cycle, with the first and second (Seattle SW and Seattle NW) through technical review as a USGS map publication. The sequence of map products is as follows (3-D maps are anticipated to lag their surficial counterparts by two calendar years):

MAP QUADRANT	SURFICIAL GEOLOGIC MAP
Seattle SW	2000 (technical review complete)
Seattle NW	2001 (technical review complete)
Seattle SE	2002 (map in progress 10/02)
Seattle NE	2003 (preexisting data acquired)

Figure 2. Map quadrangles for the City of Seattle

INVESTIGATIONS UNDERTAKEN

COMPONENT 1—REGIONAL STRATIGRAPHY AND CHRONOLOGY

We have produced a chronological and lithologic composite section of glacial and nonglacial deposits in the central Puget Lowland that is being used to evaluate the distribution, correlation, and deformation of individual geologic units across the region. This component was not originally included in this grant, but we have always acknowledged it because of its importance to localized study. No geologic study of a limited area, such as the City, can possibly succeed without also developing an adequate regional context. We have made significant progress on this component using resources from other sources, establishing regional nomenclature and descriptions that are being used by local agencies, consultants, and upcoming USGS published map products.

COMPONENT 2—SUBSURFACE GEOLOGIC DATABASE FOR THE CITY OF SEATTLE

We are building a comprehensive subsurface geologic database for the City. The database has been fully designed and its population is well over half completed (Figure 3). At present, nearly 5,000 separate geotechnical reports within the City itself, which include over 22,000 individual exploration sites, have been indexed in an MS Access database and displayed on an ArcView GIS platform. They have been obtained from the City's Department of Design,

Construction, and Land Use office (DCLU), submitted from private geotechnical consultants in support of building permit applications; from the in-house soils laboratory of Seattle Public Utilities (SPU); and from the SPU Vault, King County Department of Natural Resources Technical Library, the Washington Department of Ecology, and private consultants.

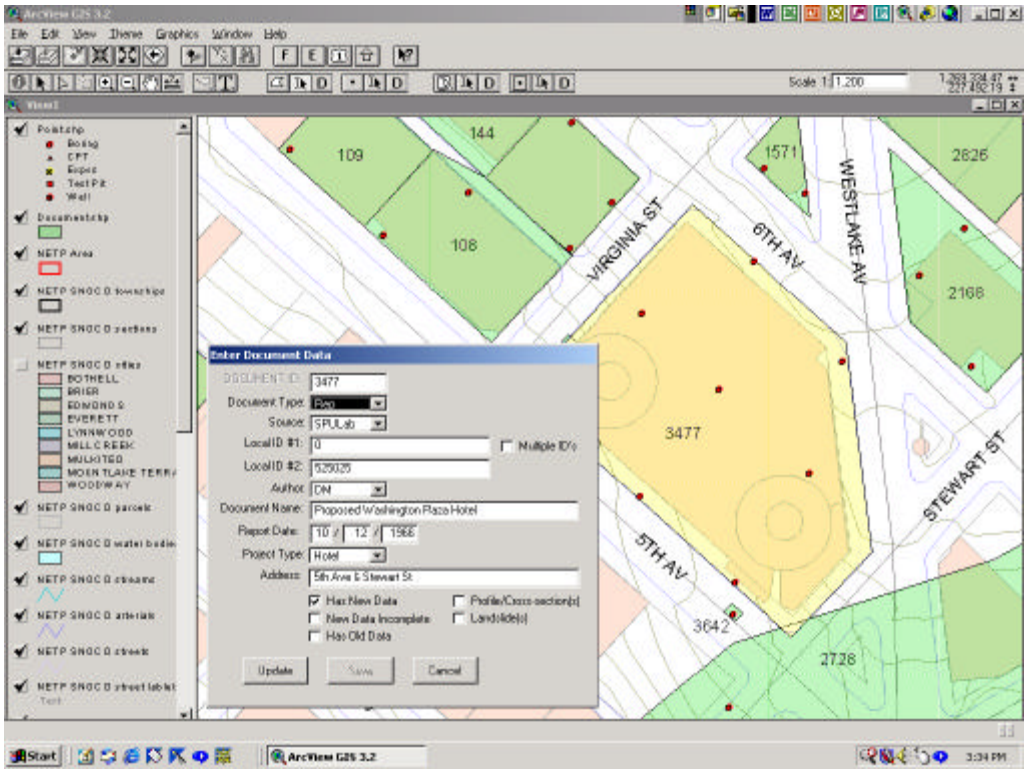

Figure 3. Data-entry screen for recording of geological reports (termed **Documents** on the screen shot). Each red point represents an individual exploration site, which has a separate screen for recording information on the geologic layers.

We have nearly completed the process of migrating the database from MS Access to a dedicated Sun workstation running Oracle database software to improve the capacity, speed, and robustness of the database.

COMPONENT 3—SURFICIAL GEOLOGIC MAPS OF THE CITY OF SEATTLE

We are preparing new geologic map coverage for the City, based on a combination of field investigations (coastal and river-valley bluffs, excavations, landslide scars) and near-surface borehole data. We have targeted first the areas with some of the greatest interest for seismic-hazard evaluation (*e.g.*, the trace of the Seattle fault, coastal landsliding, liquefaction-prone areas) and most readily available data. Fieldwork and database entry is complete for the Seattle SW and NW quadrants and nearly so for the Seattle SE quadrant, although we continue to add to the database for the SW and NW quadrangles as new documents are acquired from the City and consultants.

COMPONENT 4—THREE-DIMENSIONAL GEOLOGIC MODEL OF THE CITY OF SEATTLE

This component of the project represents the integration of all previous stages. It requires a database that is fully supported graphically: geologic materials located in space and characterized *geologically* in terms of both their material properties and their stratigraphic assignment; and *spatially* in terms of their location with respect to horizontal position, elevation, and relationship to other spatial elements such as site plans, structures and roads, and exploration point locations. Each stratigraphic unit must have a lateral and vertical definition. This component has been delayed by budgetary reductions in each prior project year, but with our efforts in 2002 significant progress has now been made in the development of a solid model (i.e. a true 3-D map) of the City of Seattle.

COMPONENT 5—EDUCATION AND TECHNICAL OUTREACH

This is an ongoing effort, anticipated to continue throughout the duration of the project. Activities are listed in the next section of this report.

RESULTS

COMPONENT 1—REGIONAL STRATIGRAPHY AND CHRONOLOGY

Over the last several years, ancillary support from NCGMP (USGS) has enabled us to work on eight 7.5-minute maps at 1:24,000 in the Seattle-Tacoma area and to initiate work on two others (Figure 4). Although not originally part of our NEHRP-funded project, this effort is critical to the geologic mapping and hazard evaluation of the City of Seattle. In mid-2002, our work under this cooperative agreement was formally redirected by the USGS Project Manager to the completion of eight 1:24,0000-scale quadrangle maps in the greater Seattle-Tacoma area, whose fieldwork and linework have been long-completed but for which support for their final completion, review, and publication had not previously been available. Seven of these maps are now largely through USGS review (Des Moines, Poverty Bay, Puyallup, Tacoma N, Tacoma S, Olalla, and Steilacoom); the eighth (Gig Harbor) will be submitted before year's end.

COMPONENT 2—SUBSURFACE GEOLOGIC DATABASE FOR THE CITY OF SEATTLE

We are rapidly populating a database of existing subsurface geologic and geotechnical data that covers not only the City of Seattle but also surrounding areas to the north and east, thanks to financial support from both this agreement and a three-year agreement with King County (2001-2003). This database accommodates both spatial and nonspatial data by following a GIS-based approach (Figure 5). The design facilitates spatial analyses, visualization, and other representations of the data, and we have developed a tool for querying individual explorations and for making cross sections directly from the database that can be displayed in ArcView (see Component 4).

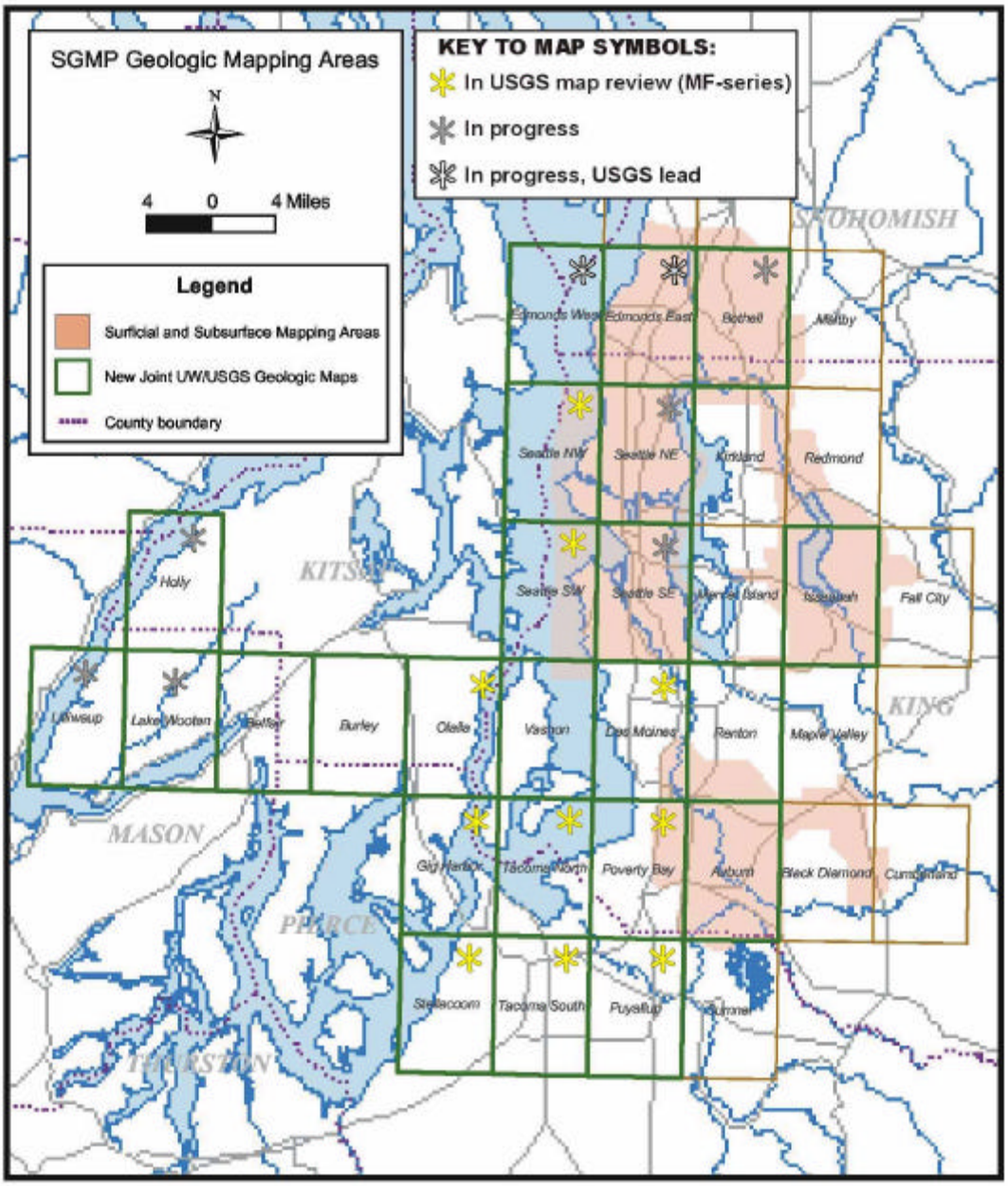

Figure 4. Status of geologic quadrangle mapping in the Puget Lowland by the University of Washington group.

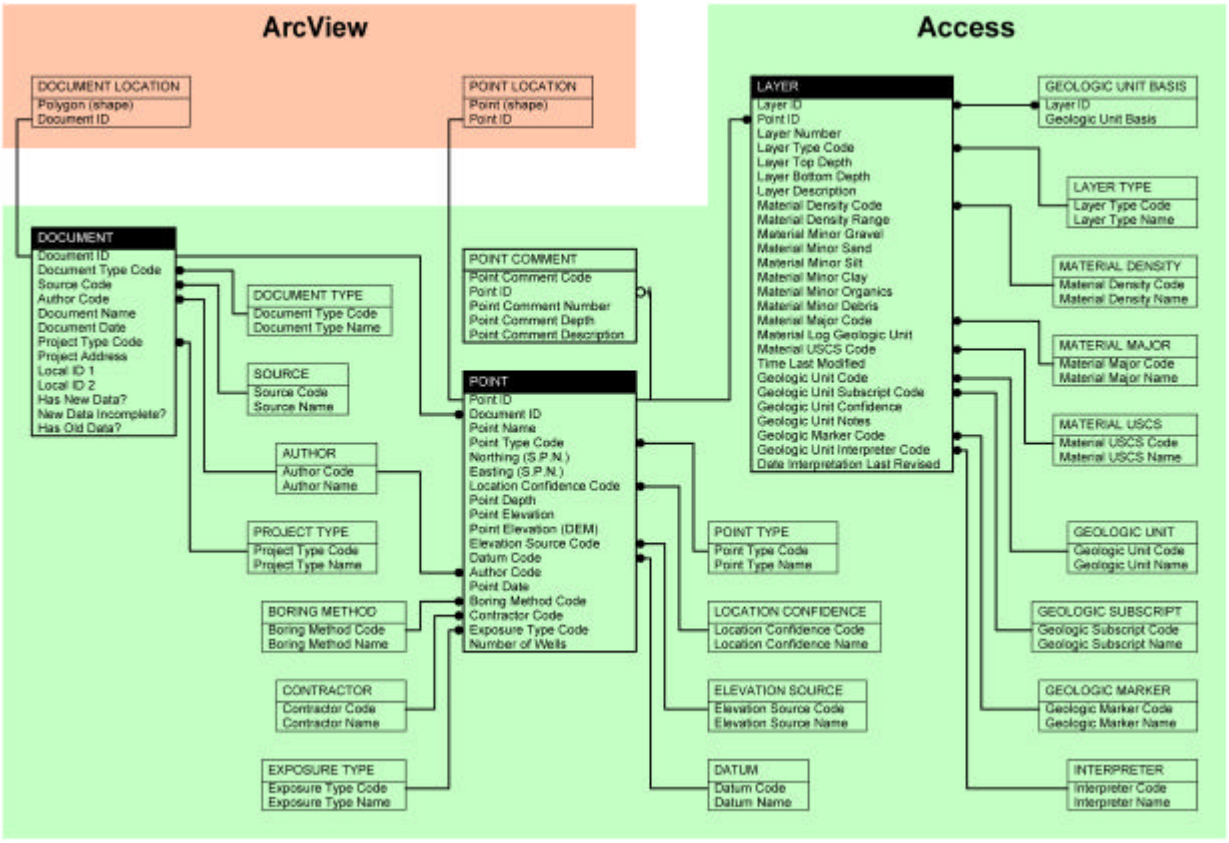

Figure 5. Database architecture. The primary elements are **DOCUMENTS** (the reports that contain the geologic and/or geotechnical information, **POINTS** (the individual exploration sites contained within a document), and **LAYERS** (the geologic strata described in an exploration).

Our progress through 2002 in populating the main tables of the database is as follows:

	Total area— to date (10/02)	**Seattle only— to date (10/02)**	**Total area — anticipated**
DOCUMENTS	7420	4486	> 12,000
POINTS	40,286	21,651	> 75,000
LAYERS	139,394	76,094	> 200,000

COMPONENT 3—SURFICIAL GEOLOGIC MAPS OF THE CITY OF SEATTLE

In this fourth year of the project, our primary emphasis has been on the acquisition of data for preparing a geologic map of the Seattle SE quadrangle. In the summer and fall of 2001, additional financial support from King County expanded or scope (and thus our map coverage)

to the north of the City as well, and this work has continued in conjunction with the mapping here in Seattle.

The Seattle SE quadrangle spans some of the most abundant data, and the most complex geology, of the city. It includes the downtown area and the industrial Duwamish Valley, and so the quantity and density of borehole data are the greatest of the region. It includes the trace of the Seattle fault zone, which nearly bisects the quadrangle from west to east. It includes most of the bedrock outcrops to be found in the City, along with a complex overlying sequence of multiple glacial and nonglacial periods that are sporadically displayed, primarily in deep borings, excavations, and tunnels for major engineering works such as the I-90 Mt. Baker tunnel, the proposed light rail tunnel through Capitol Hill, and the large downtown skyscrapers with many levels of subsurface foundation and parking.

As we are preparing the new geologic maps of the City (Figure 6), we are supplying it to researchers and City personnel alike to improve understanding of the geologic controls on these processes.

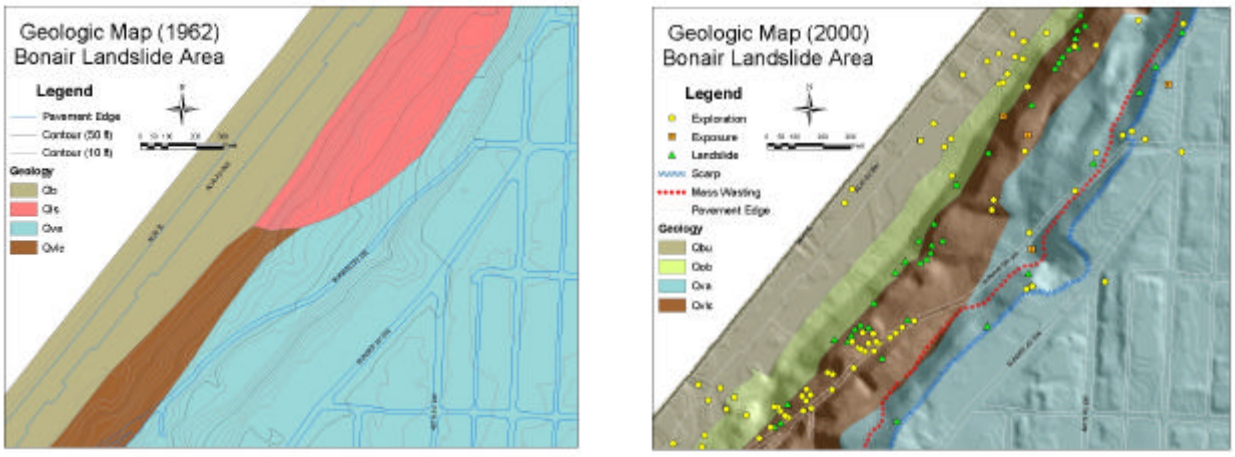

Figure 6. Example of preexisting (left) and new (right) geologic mapping. This example is from the Seattle SW quadrangle (in review). Improvements in mapping include (1) greatly increased range and quantity of data sources, particularly geotechnical explorations (yellow circles) and new field exposures (orange squares); (2) recognition of greatly expanded landslide areas (outlined by red dots) that correspond well to areas of historic landsliding (green triangles); (3) more precise delineation of geologic unit boundaries; (4) inclusion of previously unrecognized geologic units ("Qob" on the lower map); (5) more precise and intuitive rendering of topography; and (6) full digital record of all data sources, mapped contacts, and geologic interpretations.

COMPONENT 4—THREE-DIMENSIONAL GEOLOGIC MODEL OF THE CITY OF SEATTLE

This element of the project integrates each of the previous stages. The raw subsurface data is interpreted to make stratigraphic assignments, with not only the assignments themselves but also the date of any changes and the initials of the interpreter recorded in the database (Figure 7). This is an iterative process dependent upon the graphic display from the database (cross sections and surfaces), geologic mapping, and development of the stratigraphic sequence. This interpretive data set has been used to construct the conceptual 3-D model of subsurface

geology in the Seattle area, which we have first applied to the Seattle NW quadrangle (as the map area with the simplest geometry).

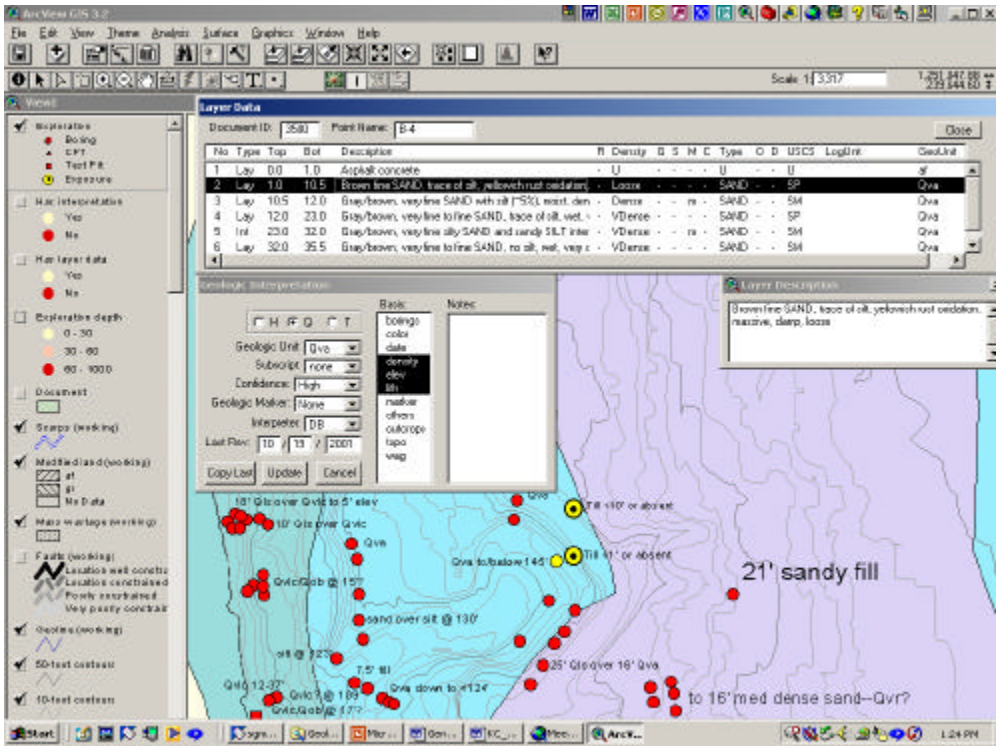

Figure 7. Screen shot of the interface for database query and interpretation. Red dots are exploration sites contained in the database. The yellow dot in the lower center part of the screen is currently selected and has its boring log displayed across the top of the screen in the "Layer Data" window. The geologist enters geologic interpretations for each layer in the left-hand window; notes also can be annotated on the screen for quick reference. The geologic contacts shown on the screen are from Waldron et al. (1962) and are being revised as part of this process.

Despite the broad spatial distribution of the down-hole data, the limited depths of most borings do not facilitate either automated interpretations of the subsurface geology or spatial interpolation of material properties. Major transit and sewer projects provide excellent but very widely spaced transects of deep, high-quality borehole data for ground truthing between outcrops. Therefore, we are not modeling the contents of the database directly. We are, however, interpreting each lithologic layer in each borehole by assigning stratigraphic units that can then be mapped individually. The surface maps, in combination with their supporting information from the database, provide an excellent foundation for developing 3-D geologic maps, where the nature and location of subsurface geologic contacts are constrained by borehole interpretations and the known or inferred processes of deposition. We have transferred these data into the software package EVS, where the geologic units in the subsurface can be attributed with the properties of the sediments with which we are familiar from surface exposures and geotechnical data. These 3-D geologic maps can subsequently be exported to construct a

subsurface model for use in groundwater, landslide, or ground-shaking applications. Our choice of EVS has been motivated in large part because of its facility in exporting data in a wide variety of formats.

Creation of a subsurface model would be impossible without the map-making sequence, since deep borings that could permit direct spatial interpolation (i.e. kriging) between observed localities are too widely spaced for the degree of geologic complexity. This process results in a model of the subsurface that makes full use of geologic interpretation.

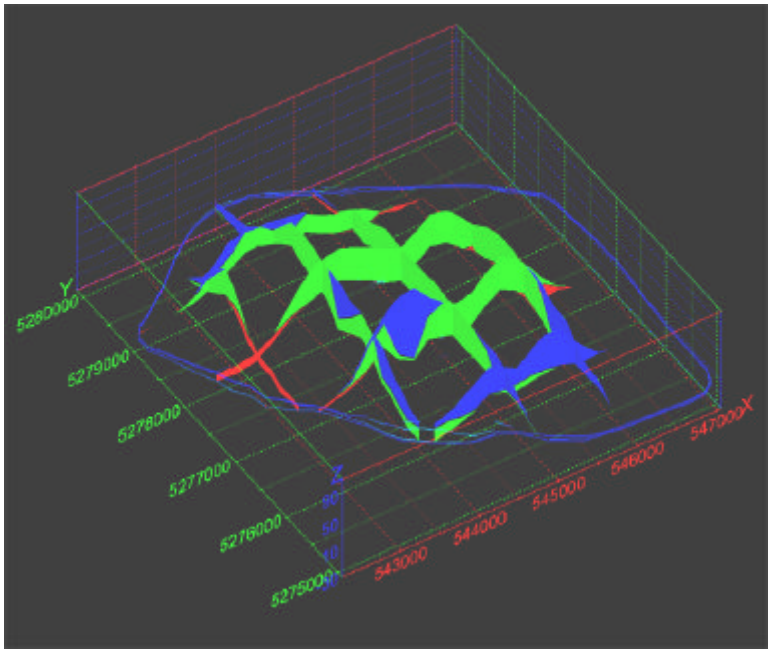

Figure 8. Cross sections at 1000-m spacing displaying the 3-D solid model of Magnolia Hill. North is to the upper right; map boundary of the Seattle NW quadrangle is along the right edge (near UTM coordinate 547000). Blue = glacial till (unit Qvt); green = advance outwash (unit Qva); red = Lawton Clay (unit Qvlc).

COMPONENT 5—EDUCATION AND TECHNICAL OUTREACH

Specific activities for this component through the end of 2002 are summarized in the following table:

ACTIVITY	DATE	AUDIENCE
SHORT COURSES—1999 - 2001		
Quaternary Geology of the Central and Southern Puget Lowland (3 days including a 1-day field trip)	April 1999 and Sept 2000	Consultants, Agency Staff, Public
Quaternary Geology of the Central and Southern Puget Lowland	Jan 2000	Nelson Couvrette Associates
Quaternary Geology of the Central and Southern Puget Lowland (2 days including field trip)	May 2000	Landau Associates
Puget Lowland Geologic Framework (1 day)	Oct 2001	King County Wastewater Treatment Division and its consultants
SHORT COURSES—2002		
Field classification and geology for drillers	September 2002	Department of Ecology-supported course for well-drilling professionals
Puget Lowland Geologic Framework (1 day)	December 2002	King County Wastewater Treatment Division and its consultants
FIELD TRIPS—1999 - 2001		
Geology of the Central Puget Lowland	June 1999	Northwest Geological Society
Geology of Seattle	June 1999 and Aug 2000	City of Seattle Staff
Geology of Seattle	Sept 2000	UW Department of Geology and Geophysics
Geology of the Seattle Southwest Quad	July 2000	Technical Advisory Group Members
Quaternary Geology of the Central and Southern Puget Lowland (2-day)	June 2000	Association of Engineering Geologists
Prehistoric Earthquake and Tsunami in the Puget Sound area	Sept 2000	WSSPC attendees: state geologists and emergency managers
Geology of Seattle	Oct 2001	Department of Earth and Space Sciences, Univ. of WA alumni

FIELD TRIPS—2002		
Geology of the Seattle Area	June 2002	Northwest Geological Society
Geology of Seattle	Nov 2002	Department of Earth and Space Sciences, Univ. of WA alumni
TECHNICAL MEETINGS—1999 - 2001		
USGS Workshop on Geologic Hazards in the Puget Lowland	Nov 2000	Emerg. Man and Geo/Eng Professionals
Project Updates	Quarterly	City of Seattle departments; King County
Technical Advisory Group Meetings	Quarterly	TAG Members
TECHNICAL MEETINGS—2002		
Project Updates	Quarterly, plus more frequent as needed	City of Seattle departments; King County
ANSS Advisory Committee (Siting sub-committee)	Quarterly, appx.	USGS, consultants, state
Technical Advisory Group Meetings	Quarterly	TAG Members
CONFERENCES—1999 - 2001		
Co-convener of the Seattle Urban Geologic Hazards Workshop	February 1999	ca. 200 agency staff and private consultants
Evening Forum on the Quaternary Geology of the Puget Lowland	August 1998; October 2000	2nd and 3rd Symposia on the Hydrogeology of Washington State
Geology of Seattle at the Seismological Society of America's Annual Meeting public forum	April 1999	SSA attendees and general public
Many individual presentations	ongoing	Professionals and research community
Convened a 1.5-day symposium on the Quaternary Geology of the Puget Lowland	April 2000	GSA attendees
Nisqually Earthquake symposium Seismological Society of America's Annual Meeting	April 2001	SSA attendees and general public
GSA North-Central Section Meeting Special Workshop on 3-D Mapping and Groundwater Modeling	April 2001	GSA Attendees
National Association of Geology Teachers, Western Division Meeting	June 2001	NAGT attendees and professionals
Convened symposium on the geology of glaciated regions at Geological Society of America annual meeting	November 2001	GSA attendees

CONFERENCES—2002		
Symposium on the Nisqually earthquake	April 2002	Annual meeting, Seismological Society of America
Symposia on the Quaternary Geology of the Puget Lowland and the Nisqually Earthquake (co-convenors and presenters)	April 2002	GSA Cordilleran Section meeting
3-D mapping workshop	October 2002	GSA Annual Meeting
PUBLIC MEETINGS AND SELECTED INVITED TALKS—1999 - 2001		
Co-convener, Urban Seismic Hazards Mapping Project Workshop	February 1999	USGS, UW, local agencies, public
Project Impact Disaster Saturdays: Display of "The Geology of Seattle" complete w/geologic samples and stratigraphic models	All, 1999, 2000, and 2001	Public
"Ground Failures from the Nisqually Earthquake" or "Geology of Seattle"	Multiple presentations	CPARM; emerg. managers; Univ. Puget Sound, K-12 classes
"Mapping the Geology of Seattle"	February 2001	Assoc. of Women in Science; Assoc. for Women Geoscientists
NOAA Tsunami Workshop	February 2001	Emergency managers
PUBLIC MEETINGS AND SELECTED INVITED TALKS—2002		
Invited presentations at Seismological Society of America annual meeting and Geological Society of America Cordilleran section meeting	April 2002	SSA, GSA
"The Seattle-Area Geologic Mapping Project"	October 2002	Local chapters, Association of Engineering Geologists & American Society of Civil Engineers
Brown-bag presentations on Seattle-area geology to local consulting firms	June 2002, September 2002	GeoEngineers; Landau and Associates

Local Agency and Public Outreach. Because of the potential utility of the geologic map products, and because of the efforts being invested by this project on behalf of geologic studies by *all* scientists throughout the region, we have received unprecedented support from local governments. The value of these efforts has been directly articulated (see *Appendix)* and is more substantively demonstrated by the successful leveraging of USGS NEHRP funds (see *Financial Notes* section, below).

The geologic and engineering consultants of the region recognize our leadership in defining the stratigraphy, lithology, and geologic history of this area. They frequently solicit our opinions regarding various specific sites, and they utilize our database and our mapping efforts in their

own investigations, which we provide in exchange for additional data. They also now utilize the nomenclature and color scheme for the region that we have established through this project.

Technical Advisory Group (TAG). A TAG was established early in our first year to enhance communication between this project and the end users of the products, consultants and agency representatives. Its membership (53 counting Troost and Booth) emphasizes senior members of the region's geologic, geotechnical, hydrogeologic, and engineering consulting firms; and representatives from state, city, and local agencies who will be both the major users and the major contributors. It is a veritable "who's who" of the professional Seattle-area geologic community and meets quarterly. The following list provides the entities represented on the TAG:

Consulting Firms

AMEC
Aspect Consulting LLC
Associated Earth Sciences
Boeing Aerospace Company
Cascade Drilling
CDM Jessberger
Environmental Partners
R. Free Consulting
Galster Consulting
GeoEngineers, Inc.
Golder Associates, Inc.
Hart Crowser
Herrera Consultants
HWA Geosciences
Landau Associates
Nelson Geotechnical
Robinson & Noble, Inc.
Roth Consulting
SCS Engineers
Shannon & Wilson, Inc.
Terra Associates
Tubbs Geosciences
Udaloy Environmental Services
URS Corporation
Yonemitsue Geological Services

Agencies

City of Seattle – Design, Construction, and Land Use; Seattle Public Utilities; Parks Department
City of Tacoma
Island County Health Department
King County Department of Natural Resources
King County Wastewater Treatment Div
King County DDES
US Army Corps of Engineers
US EPA
USGS – Water Resources & Geologic Divisions
University of Washington
WA Dept. Nat.l Res., Div. Of Geology & Earth Res. & BSSD
Washington Department of Ecology
Washington Dept of Transportation

NON-TECHNICAL SUMMARY
Project period January 1, 2001 – December 31, 2001

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Cooperative Agreement Number: 01HQAG0017

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Telephone: (206) 543-7923, FAX: (20) 685-3836 dbooth@u.washington.edu
http://www.geology.washington.edu/sea-geo

NEHRP Element: I, Pacific Northwest region **Keywords**: Geologic Mapping, Surficial Deposits, Age Dating, Tectonic Structures

Many engineering applications in urban and urbanizing areas depend on the spatial distribution of geologic materials and the sequence and history of their deposition. This project is mid-way through developing a detailed understanding and representation of the three-dimensional distribution of geologic materials beneath Seattle. To date, we have acquired and organized nearly 40,000 items of geologic information, representing a substantial start on of the vast amount of existing data; in combination with our ongoing field investigations, we have begun preparing and publishing the geologic maps that will display this information for scientists, agencies, and the public.

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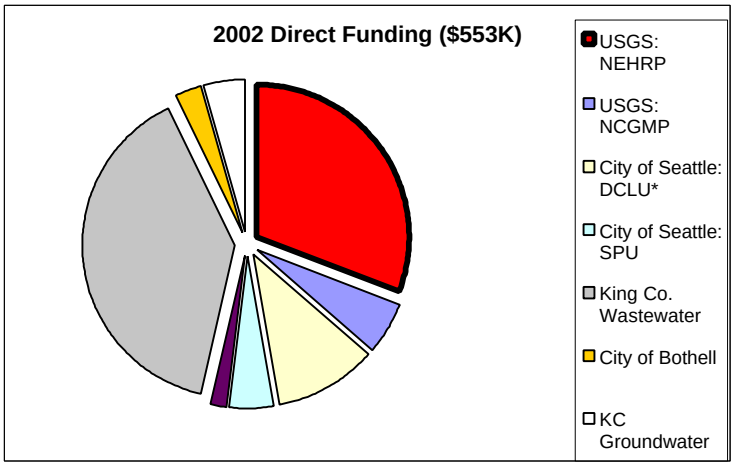
FINANCIAL NOTES

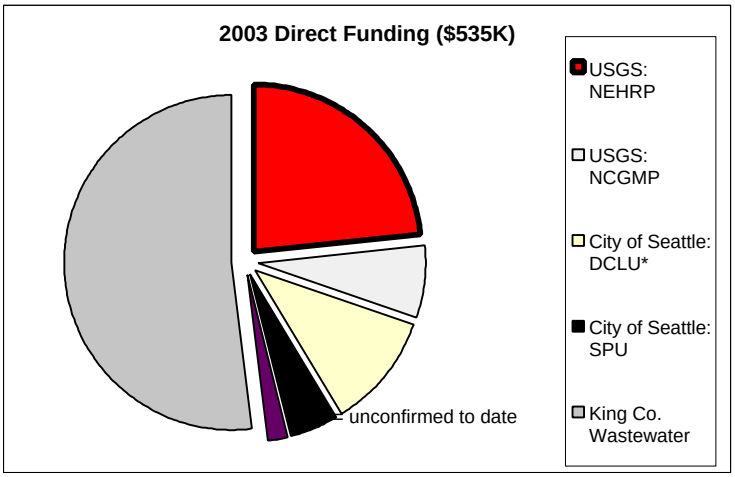
This project has been quite successful in leveraging the contribution of the USGS NEHRP funds through additional financial and in-kind support from other programs of the USGS and from local governments. Some of that support has been used to cover the initial shortfall of funds for the originally scoped NEHRP project (geologic map of the City of Seattle), some has been used to provide the regional geologic framework (Component 1 of this project), and some has been used to expand the geographic scope of the effort into populated areas to the north and east. Funding amounts are tabulated and also shown graphically on the next page:

Actual and Anticipated Project Funding 2000-2003:

DIRECT FUNDING

SOURCE	*2000*	*2001*	*2002*	*2003*
USGS: NEHRP	$160,000	$170,000	$170,000	$125,000
USGS: NCGMP	$38,332	$12,450	$31,617	$36,975
City of Seattle: DCLU	$60,000	$60,000	$60,000	$60,000
City of Seattle: SPU	$50,000	$25,000	$25,000	$25,000
Univ. of WA: CUWRM	$20,000	$10,000	$10,000	$10,000
King Co. Wastewater		$327,449	$216,600	$278,420
City of Bothell			$15,000	$0
KC Groundwater project			$25,000	$0
	$328,332	**$604,899**	**$553,217**	**$535,395**





Support letter from King County to USGS (6/25/01):

King County
Wastewater Treatment Division
Department of Natural Resources
201 South Jackson Street
Seattle, WA 98104-3855

June 25, 2001

Martha Garcia
Peter Lyttle
Co-Coordinators National Cooperative
Geologic Mapping Program
12201 Sunrise Valley Drive, MS 908
Reston, VA 20192

Dear Ms. Garcia and Mr. Lyttle:

Over the next few years, King County will be designing and constructing nearly $1.1 billion of new wastewater facilities in North King County and South Snohomish County (north of the City of Seattle). We understand that the United States Geological Survey (USGS), in cooperation with the University of Washington, is proposing to create a seamless, 7.5' digital geologic map database of the central Puget Sound. Such a database will be invaluable to our current and future planning, design and construction efforts, and, in fact, King County is providing direct logistical and financial support to this effort through agreements with the University.

We strongly support the development of this database and are gratified that the USGS geologists are working with geologists from the University of Washington's Seattle-Area Geologic Mapping Project to complete mapping in the area where we are constructing these new facilities. We will continue to explore opportunities for continued cooperative relationships with the USGS and the University of Washington to ensure that geologic mapping in areas covering the Edmonds, Edmonds East, and Bothell 7.5' Quadrangles in particular, is completed in a timely manner.

Sincerely,

Pam Bissonnette

Pam Bissonnette
Director

cc: Doug Theiler, Manager, Department of Natural Resources (DNR),
Wastewater Treatment Division (WTD)
Christie True, Manager, Planning & System Development, (WTD)
Bob Peterson, Project Manager, Conveyance System Improvements, (WTD)